PTO 08-5132

CC=JP DATE=20010821 KIND=A
PN=2001226741

High Strength Cold Rolled Steel Sheet Excellent in Strength and Flanging Workability and Method for Producing Same

[Nobi-Huranji Kakōsei-ni Sugureta Kō-Kyōdo Reien Kōban oyobi sono Seizō Hōhō]

Hidenao Kawabe, et al.

UNITED STATES PATENT AND TRADEMARK OFFICE
Washington, D.C. May 2008

Translated by: FLS, Inc.

PUBLICATION COUNTRY	(19):	JP
DOCUMENT NUMBER	(11):	2001-226741
DOCUMENT KIND	(12):	A
PUBLICATION DATE	(43):	20010821
APPLICATION NUMBER	(21):	2000-36757
DATE OF FILING	(22):	20000215
ADDITION TO	(61):	NA
INTERNATIONAL CLASSIFICATION	(51):	C 22 C 38/00; C 21 D 9/46; C 22 C 38/14, 38/58
PRIORITY	(30):	NA
INVENTORS	(72):	KAWABE, HIDENAO; SHIMIZU, TETSUO; FURUKIMA, OSAMU
APPLICANT	(71):	KAWASAKI STEEL CORP.
DESIGNATED CONTRACTING STATES	(81):	NA
TITLE	(54):	HIGH STRENGTH COLD ROLLED STEEL SHEET EXCELLENT IN STRENGTH AND FLANGING WORKABILITY AND METHOD FOR PRODUCING SAME
FOREIGN TITLE	[54A]:	NOBI-HURANJI KAKOSEI-NI SUGURETA KO-KYODO REIEN KOBAN OYOBI SONO SEIZO HOHO

[Claims] [*]

[Claim 1] a high-strength cold rolled steel sheet having excellent flanging workability containing

C: 0.05 to 0.15 %
Si: 0.05 to 0.50 %,
Mn: 2.5 to 3.5 %
P: 0.02 % and under,
S: 0.0035 % and under
Al: 0.01 % and under,
Ti: 0.001 % and greater and less than 0.05 %
Nb: 0.005 to 0.08 %

at percent by mass, having a composition comprised of stock Fe and the inevitable impurities; having a texture containing fine bainite having an average crystal grain size of 5.0 μm and under at a percentage of at least 80 %; having a strength-elongation balance TS X E1 of 19000 MPa % and above, a strength-hole expanding ratio balance TS x λ of 74000 MPa % and above.

[Claim 2] A high-strength cold rolled steel sheet having excellent flanging workability as described in Claim 1, characterized as containing Group 1 or Group 2 selected from among Group A and Group B below at a percent by mass in addition to the abovementioned composition:

One or two or more types from Group A as follows, Cr: 0.01 to 0.5 %; Cu: 0.01 to 1.0 %; Ni: 0.01 to 1.0 %, Mo: 0.01 to 1.0 %; V: 0.01 to 0.3 %; Zr: 0.01 to 0.3 %; B: 0.0001 to 0.005 %;

One or two or more types from Group B: Ca: 0.0001 to 0.005 %; REM: 0.0001 to 0.005 %.

---

[*] Claim and paragraph numbers correspond to those in the foreign text.

[Claim 3] A method for producing a high-strength cold rolled steel sheet having excellent flanging workability containing

C: 0.05 to 0.15 %
Si: 0.05 to 0.50 %
Mn: 2.5 to 3.5 %
P: 0.02 % and under,
Ti: 0.001 % and above and less than 0.05 %
Nb: 0.005 to 0.08 %

as percent by mass, by either reheating a steel material having a texture comprised of stock Fe and the inevitable impurities at a temperature of 1050 to 1250°C or carrying out hot rolling after a temperature of 1050 to 1250°C is reached with a finishing temperature FDT of 850 to 950°C, starting cooling to within 0.5 second after said hot rolling has been finished, cooling at a cooling velocity of 30°C and above, making a winding hot rolled sheet at 350 to 550°C, then carrying out cold rolling on said hot rolled sheet, then producing a cold rolled sheet, then carrying out continuous annealing at an annealing temperature within a range of (Ac_3 transformation point) to (Ac_3 transformation point + 100°C), and quenching up to a temperature range of 200 to 400°C at a cooling velocity of 40°C/s and above to 100°C/s from the annealing temperature.

[Claim 4] A method for producing high-strength cold rolled steel sheet having excellent flanging workability as described in Claim 3 which contains 1 group or 2 groups selected from Group A and Group B as follows at a percent by mass in addition to the abovementioned composition.

One or two or more types from:

Group A: Cr: 0.01 to 0.5 %; Cu: 0.01 to 1.0 %; Ni: 0.01 to 1.0 %; Mo: 0.01 to 1.0 %; V: 0.01 to 0.3 %; Zr: 0.01 to 0.3 %; B: 0.0001 to 0.005 %;

One or two or more types from

Group B: Ca: 0.0001 to 0.005 %; REM: 0.0001 to 0.005 %.

[Detailed Description of Invention]

[0001] [Technical Field]

The present invention relates to a high-strength cold rolled steel sheet having a tensile strength of 780 MPa and above which is suitable for use in door impact beams, bumpers and other parts used to improve the collision safety of automobiles of automobile parts, and in particular to an improved ductility and flanging workability.

[0002] [Description of the Prior Art]

In recent years, there has been a demand for the use of high-strength thin steel sheets used for automobile parts to improve the safety of the automobile and to lighten the weight of the chassis. There has always been a particular demand for a high strength of 780 MPa and above for bumper parts used to inhibit deformations in the cabin during collisions as well as steel sheets used in bumper parts and impact beams. There has also been a demand for a steel sheet having a tensile strength of 780 MPa and above to meet the demand for a thinner [sheet] due to the trend to higher strength steel. There has also been a demand for outstanding ductility, bending

formability, flanging workability and the like in addition to having high strength for steel sheets used for bumper parts and door impact beams and the like.

[0003] Working reinforcement, texture reinforcement and deposition reinforcement and the like were well known in the prior art as a reinforced mechanism for steel. While the strength increases readily by using these reinforcing mechanisms, the ductility declines as the strength increases and the workability deteriorates. The higher the strength, the more marked is the deterioration of the workability. There has been a proposal for a complex texture steel sheet (dual phase steel sheet) having ferrite as the main phase and martensite, bainate and the like as the second phase as a high tension steel sheet used to prevent deterioration of the workability in this way. For example, Laid-Open Patent Specification H04-236741 discloses a fused zinc plated steel sheet having a complex texture having ferrite as its main phase, having a tensile strength of 80 kgf/mm^2 (780 MPa) and above and a yield ratio of 60 % and under. However, the steel sheet disclosed in Laid-Open Patent Specification H04-236741 has an outstanding workability characterized as a strength (TS)-elongation (EI) balance (TS x EI) of 17000 to 25000 MPa %. However, there were problems in that the strength (TS)-hole expanding rate (λ) balance is by no means sufficient and it was insufficient compared to the value required for the recent automobile parts steel material. This is thought to be because of the lack of textural

uniformity, the local inclusion of the hard phase and the soft phase so that there are a great many sites which are starting points for cracks during hole expanding tests, the hole expanding rate declines and the flanging workability is not sufficient.

[0004] In addition, Laid-Open Patent Specification H04-235253 discloses an ultra-high strength cold rolled steel sheet having a yield ratio of 80 % and above. This steel sheet contains C: 0.10 to 0.20 %; Si: 0.20 % and under; Mn: 2.0 to 3.5 %; Cr: 0.20 to 1.00 %; Nb: 0.005 to 0.050 %; B: 0.0003 to 0.0020 %; Al: 0.020 to 0.100 % as percent by weight. Further, there are no restrictions on the amount of P, S and N used, and the tissue is a cold rolled steel sheet having a texture for the bainite main body containing 5 to 15 % of residual austenite. This steel sheet was produced by heating a steel raw material to 1200°C and above, carrying out finishing rolling at a temperature of 800°C and above, then winding it at 750 to 550°C, then cold rolling it at a yield of at least 40 %, continuously annealing this at 800 to 900 °C at a soaking of 20 to 300s, then quenching at up to 450 to 300 °C and then slow cooling it. However, the steel sheet described in Laid-Open Patent Specification H04-235253 has a low elongation and does not have sufficient workability to satisfy the required value for steel material for automobile parts.

[0005] In addition, Laid-Open Patent Specification H07-188767 discloses a method for producing high-strength cold rolled steel sheets having excellent flanging characteristics. This technique is

used to obtain high-strength cold rolled steel sheets having a bainite main body texture and flanging characteristics of a tensile strength of 780 MPa and above by making a steel sheet including C:0.03 to 0.10 %, Si: 0.3 to 1.0 % and Mn: 1.6 to 3.0 % as percent by weight or making a steel sheet by hot rolling and cold rolling of steel containing at least one of the following: Ti, Nb and B, then annealing this steel sheet at a transformation point of at least A_3 at a temperature of 900 °C and under, quenching it up to 200 to 300 °C at a cooling velocity of 100 to 500 °C/second from a temperature of at least 600 °C, then maintaining the temperature or reheating it at 200 to 400 °C or reheating it. However, the steel sheet produced by using the technique described in Laid-Open Patent Specification H07-188767 has a strength-expansion balance (TS x E1) of approximately 14000 to 17000 MPa % and does not have sufficient workability required to satisfy the values required for current automobile parts steel materials.

[0006] In addition, Laid-Open Patent Specification H10-237547 discloses high ductility, high-strength cold drawn steel sheets. These steel sheets are cold drawn steel sheets containing C: 0.08 to 0.30 %, Si: 0.1 to 2.5 %; Mn: 0.5 to 2.5 % as well as Ca: 0.0010 to 0.0100 % percent by weight having a structure comprised of low-temperature transformed product or at least 40 % of a low-temperature transformed product and stock ferrite, having the stipulated hardness of a low-temperature transformed product. These steel sheets are cold

rolled, then recrystallized and annealed at a temperature having a transformation point of at least A_{C1}, then forcibly air-cooled, quenched at at least 100 °C/second from a temperature region of 450 to 800 °C and subjected to over-aging processing. However, the steel sheet described in Laid-Open Patent Specification H10-237547 has a strength (TS)-hole expanding ratio (λ) (TS x λ) balance of approximately 65000 MPa % and under and a low hole expanding workability and does not have sufficient workability to satisfy the values required for current automobile part steel materials.

[0007] [Problems Which the Present Invention is Intended to Solve]

It is an object of the present invention to solve the abovementioned problems associated with the prior art and provide a high-strength cold rolled steel sheet, having a tensile strength of at least 780 MPa, excellent strength-expanding balance and strength-hole expanding ratio balance and excellent flanging workability as well as a method for producing it. Furthermore, the target value of the strength-expanding balance for the steel sheet in the present invention should be TS x EI of 19000 MPa % and above, the target value for the strength-hole expanding ratio balance which is one indicator of the flanging workability should be at least TS x λ of 74000 MPa. Furthermore, λ is the hole expanding ratio (%).

[0008] [Means Used to Solve the Problem]

The inventors carried out a great deal of research on solving the abovementioned problems from the vantage points of the steel

constituents, the production conditions, the metal structure and the like. They found that it was possible to obtain a structure having as main phase fine bainite having an average crystal grain size of 5.0 μm by adjusting the steel composition and the production conditions to an appropriate range, uniformly refining the structure prior to cold rolling and adjusting the cold rolling and annealing conditions. As a result, they found this to be a high-strength steel sheet wherein the starting points for cracks occurring during processing were reduced, which had a high strength—expanding balance and strength-hole expanding ratio balance not seen in the prior art, without any lowering in the strength level and the press forming characteristics were improved.

[0009] The present invention was completed after a great deal of research based on the abovementioned findings. This means that the present invention is a high-strength cold rolled steel sheet containing C: 0.05 to 0.15 %; Si: 0.05 to 0.50 %; Mn: 2.5 to 3.5 %; P: 0.02 % and under; S: 0.0035 % and under; Al: 0.1 % and under; Ti: 0.001 % and above to less than 0.05 %; and Nb: 0.005 to 0.08 % at percent by mass; it has a structure comprised of stock Fe and the inevitable impurities, containing at least 80 % fine bainite having an average crystal grain size of 5.0 μm and under, a tensile strength of at least 780 MPa, a strength-expanding balance TS x El of at least 19000 MPa % and a strength-hole expansion ratio balance of TS x λ of 74000 MPa %. In addition, the following from Group A and Group B at

percent by mass should be used in the present invention in addition to the abovementioned composition:

One or two or more types from

Group A: Cr: 0.01 to 0.5 %; Cu: 0.01 to 1.0 %; Ni: 0.01 to 1.0 %; Mo: 0.01 to 1.0 %; V: 0.01 to 0.3 %; Zr: 0.01 to 0.3 %; B: 0.0001 to 0.005 %;

One or two types from the following

Group B: Ca: 0.0001 to 0.005 %; and REM: 0.0001 to 0.005 %.

[0010] In addition, the second invention is a method of producing a high-strength, cold rolled steel sheet having an excellent flanging workability characterized as a steel raw material containing C: 0.05 to 0.15 %; Si: 0.05 to 0.50 %; Mn: 2.5 to 3.5 %; P: 0.02 % and under; S: 0.0035 % and under; Al: 0.1 % and under, Ti: not less than 0.001 % and not more than 0.05 %; Nb: 0.005 to 0.08 % at percent by mass and comprised of a composition of stock Fe and the inevitable impurities, which is reheated at a temperature of 1050 to 1250°C or once it reaches a temperature ranging from 1050 to 1250°C, hot rolling is carried out at a finishing rolling final temperature FDT of 850 to 950°C, cooling is started within 0.5 seconds after said hot rolling is completed, cooling is carried out at a cooling velocity of 30°C/s and above, it becomes a coiling hot-rolled sheet at 350 to 550°C, then cold rolling is carried out on said hot rolled sheet making it a cold rolled sheet; annealing is carried out

continuously on said cold rolled sheet at an annealing temperature within the range of a (transformation point of A_{C3}) to (transformation point of A_{C3} + 100°C) and quenching is carried out from said annealing temperature to a temperature range of 200 to 400°C at a quenching velocity of not less than 40°C/s and less than 100°C/s. In addition to the abovementioned composition, the second invention may contain one or two groups from Group A or and Group B at a percent by mass as follows.

Group A: one or two or more types from the following:

Cr: 0.01 to 0.5 %; Cu: 0.01 to 1.0 %; Ni: 0.01 to 1.0 %; Mo: 0.01 to 1.0 %; V: 0.01 to 0.3 %; Zr: 0.01 to 0.3 %;

B: 0.0001 to 0.005;

Group B: one or two or more types from the following:

Ca: 0.0001 to 0.005 %; and REM: 0.0001 to 0.005 %.

[0011] [Mode of Working the Invention]

First, we shall explain the reason for restricting the chemical composition of the high-strength cold rolled steel sheet in the present invention. Furthermore, "percent by mass" simply indicates percentage unless otherwise indicated.

C: 0.05 to 0.15 %

C is an austenite stabilized element which acts effectively on the transformation composition reinforcement which reinforces the steel using the low-temperature transformation phase. In order to obtain a tensile strength of at least 780 MPa, the composition of the element

should be at least 0.05 %. Meanwhile, when more than 0.15 % is contained, the weldability and workability deteriorate. As a result, C has been restricted to a range of 0.05 to 0.15 %. Further, it should be 0.07 to less than 0.10 %.

[0012] Si: 0.05 to 0.50 %

Si is an element which contributes to increasing the strength, and in the present invention, it should be contained at 0.05 % and above. Meanwhile, when it exceeds 0.50 %, ferrite transformation is promoted, the low-temperature transformation phase is not formed in the desired amount and the strength is insufficient. As a result, Si is restricted to a range of 0.05 to 0.50 %. Further, it should be 0.10 to less than 0.30 %.

[0013] Mn: 2.5 to 3.5 %

Mn is an element which bonds with S and is effective in preventing heat cracks caused by S. It is added according to the amount of S contained. In addition, Mn permits an action which lowers the A_{r3} transformation point, contributes to refining of the crystal grains and increases the strength-expansion balance. In addition, Mn enhances the quenching characteristics of the steel, inhibits the formation of ferrite and pearlite, particularly in the cooling process of the cold rolling and annealing. It provides a structure having a stable main bainite phase and provides it with a remarkably high strength. Although this effect is confirmed at a content of at least 2.5 %, the effect is saturated even when it is contained in

excess of 3.5 %. As a result, Mn is restricted to a range of 2.5 to 3.5 %. Furthermore, it should be 3.10 to 3.40 %.

[0014] P: 0.02 % and under

P acts to prevent hydrogen embrittlement and delayed fracture caused by hydrogen which has accumulated in the steel. However, when it is contained in excess, it causes a lack of uniformity in the structure and the solidification segregation during casting is marked. As a result, P is restricted to 0.02 % and under. Furthermore, it should be 0.005 to 0.015 %.

[0015] S: 0.0035 % and under

S is present in the steel as a sulfide. It is a source of stress concentration and lowers the flanging workability and other types of workability. As a result, S should be reduced as much as possible. However, as long as it is less than 0.0035 %, the hole expanding workability is not adversely affected even in the high-strength materials which are the objective of the present invention. As a result, S is restricted to 0.0035 % and under. Furthermore, it should be 0.0020 % and under.

[0016] Al: 0.1 % and under

Al acts as a deoxidizing agent. It also improves the yield of Ti, Nb and other carbide and nitride forming elements. At the same time, it is an element which refines the crystal grains. However, when the content exceeds 0.1 %, oxide group inclusions are increased, the degree of cleaning is lowered and the surface characteristics and

workability deteriorate. As a result, Al is restricted to 0.1 % and under.

[0017] Ti: not less than 0.001 % and less than 0.05 %

In the present invention, Ti is an extremely important element along with Nb. It affects the recrystallization temperature and acts effectively on the uniform refining of the structure. In addition, Ti is used in combination with Nb to control the ferrite transformation so that the minimum cooling velocity of the ferrite formation declines and the quenching characteristics are improved. As a result, it is effective in that the bainite structure can be readily obtained in the cooling process after cold rolling has been carried out. This type of effect is confirmed at a content of 0.001 % and above when combined with Nb. Meanwhile, the effect is saturated when contained at 0.05 % and above and the effect cannot be expected to correspond to the amount contained so that it is economically unfeasible. Therefore, Ti is restricted to at least 0.001 % and less than 0.05 %. Furthermore, 0.01 to 0.03 is preferable.

[0018] Nb: 0.005 to 0.08 %

Nb is deposited in the form of NbC. It influences the form of the deposit and the recrystallization temperature when used in combination with Ti and acts effectively on the uniform refining of the composition. Nb also inhibits formation of ferrite-pearlite and facilitates formation of a main structure of bainite and has the effect of improving the ductility and hole expanding workability

regardless of the high strength. This effect is confirmed at 0.005 % or greater. However, when contained in excess of 0.08 %, large amounts of hard deposits form in the steel and the flanging workability is lowered. As a result, Nb is restricted to within the range of 0.005 to 0.08 %. Furthermore, a range of 0.03 to 0.07 % is preferable.

[0019] In addition to the abovementioned composition, elements contained in one group or two groups selected from Group A and Group B as follows may be used as needed in the present invention.

One or two or more types from

Group A: Cr: 0.01 to 0.5 %; Cu: 0.01 t0 1.0 %; Ni: 0.01 to 1.0 %; Mo: 0.01 to 1.0 %; V: 0.01 to 0.3 %; Zr: 0.01 to 0.3 %; and B: 0.0001 to 0.005 %. Cr, Cu, Ni, Mo, V, Zr and B are elements which increase the strength of the steel and one, two or more types of these elements may be selected and contained.

[0020] Cr, Cu, Ni and Mo are elements which are effective in inhibiting a decline in elongation so that it is comparatively low and in increasing the strength of the steel. It is confirmed to be effective when contained at 0.01 %. Furthermore, even when the content of C exceeds 0.5 % and the content of Cu, Ni and Mo exceed 1.0 %, the effect is saturated and an effect commensurate with the amount contained cannot be expected. As a result, Cr should be within the range of 0.01 to 0.5 %; Cu should be 0.01 to 1.0 %; Ni should be 0.01 to 1.0 %; and Mo should be 0.01 to 1.0 %. Furthermore, Cr should

be in the range of 0.1 to 0.3 %; Cu should be in the range of 0.1 to 0.5 %; Ni should be within the range of 0.1 to 0.5 %; and Mo should be within the range of 0.1 to 0.5 %.

[0021] V and Zr are elements which are used to increase the strength of the steel and to increase the local expansion. Although this type of effect is confirmed when these are contained respectively at 0.01 % to 0.3 %, the effect is saturated even when these are contained respectively in excess of 0.3 % and an effect commensurate with the amount contained cannot be expected. As a result, V and Zr should be contained respectively within a range of 0.01 to 0.3 %. Furthermore, a range of 0.01 to 0.1 % is preferable for V and a range of 0.01 to 0.1 % is preferable for Zr.

[0022] B is an element which is used to increase the quenching characteristics, prevent deposition of ferrite and other soft phases, facilitate bainite phase formation and to increase the strength of the steel. This effect is confirmed at a content of 0.0001 % and above. Furthermore, no further increase in the effect can be obtained even when the content is 0.0001 % or above. Therefore, the content of B should be in the range of 0.0001 to 0.005 %. Furthermore, a range of 0.0001 to 0.0020 % is preferable.

[0023] Group B: one type or two types of the following: Ca: 0.0001 to 0.005 %; and REM: 0.0001 to 0.005 %

Ca and REM are used to make the sulfide inclusions spheroid and to reduce the source of stress concentration; they have the effect of

increasing the flanging workability and are contained as needed in the present invention. These effects are confirmed for both Ca and REM at a content of 0.0001 % and above. However, the effect is saturated even at a content exceeding 0.005 % and an effect commensurate with the amount contained cannot be expected. As a result, the content of Ca should be within the range of 0.0001 to 0.005 % and the content of REM should be within the range of 0.0001 to 0.005 %.

[0024] Furthermore, the residue of constituents other than those indicated above consists of Fe and the inevitable impurities. The inevitable impurities can be permitted within a range of N: 0.0060 % and under and O: 0.0060 % and under. The steel sheet in the present invention having the composition indicated above has a structure of fine bainite which has an average crystal grain size of 5.0 μm and under at an area rate of 80 % and under. The structure in the present invention contains fine bainite as the main phase at 80 % and above in terms of percentage evaluated at the surface rate. Other than pearlite, ferrite, martensite, pearlite and residual austenite should be contained at a total area rate of 20 % and under and preferably 10 % and under as a secondary phase. When the secondary phase exceeds 20 %, the hole expanding ratio deteriorates. By using a structure mainly of bainite, a high strength can be obtained and a flanging workability can be obtained which is greatly improved over other

compositions (such as a complex composition of ferrite and martensite) having the same strength.

[0025] In addition, the composition of the steel sheet in the present invention has as its main phase fine bainite having an average crystal grain size 5.0 μm and under. In the present invention, measuring the crystal grain size involved measuring the entire thickness of the sheet. The cross-section in the rolling direction and the cross-section in the direction perpendicular to the rolling direction were measured based on the stipulations of JIS G 0552 and is indicated as the mean value of these. The flanging workability and the hole expanding workability are improved by using a fine structure having an average crystal grain size of 5.0 μm and under. Furthermore, when a high degree of flanging workability is required, the average crystal grain size should be 3.0 μm and under. Furthermore, the Mn, Ti, Nb and other alloy elements mentioned above must be used in combination in an appropriate amount to obtain a structure whose main phase is bainite having an average crystal grain size of 5.0 μm and under and preferably 3.0 μm and under. At the same time, the hot rolling conditions (to be discussed further on) as well as the annealing and post-annealing cooling conditions should be controlled as appropriate.

[0026] By using the abovementioned composition and making adjustments to it, a high-strength cold rolled steel sheet can be obtained which has a tensile strength of 780 MPa and above, a

strength—elongation balance TS x El of 19000 MPa % and above and a strength-hole expanding rate balance TS x λ of 74000 MPa % and above. Next, we shall describe the method of preparing the steel sheet in the present invention. Ingot steel having the abovementioned composition should be produced using a converter or electric furnace or other usual well-known ingot steel forming method to make slag or other steel raw material using the continuous casting method. Needless to say, the ingot-making method, thin slag casting method or other methods may be used instead of the continuous casting method. Hot rolling is carried out on this steel raw material to form a hot rolled sheet.

[0027] Hot rolling involves cooling the steel raw material to room temperature and then reheating it or placing it in a heating furnace while hot without cooling it to room temperature, heating it and directly rolling it or keeping it at a low temperature and then carrying out direct rolling. In addition, continuously cast slag may be directly hot rolled as in the thin slag continuous casting method.

[0028] Reheating temperature of steel raw material: 1050 to 1250°C

As low a temperature as possible such as 1250°C should be used when reheating and it should preferably be reheated to 1150°C and below and 1050°C and below so that the initial austenite grains can be uniformly refined. In addition, even when straightforward rolling and direct rolling are carried out, the temperature should be 1250°C and under and 1050°C and above and then rolling should be started.

When the temperature exceeds 1250°C, the crystal grains become large and coarse so that it is difficult thereafter to refine the structure using hot rolling. Furthermore, a heating temperature of 1050°C and above should be used to secure the finishing rolling temperature.

[0029] Finishing rolling completion temperature FDT: 850 to 950°C

In the present invention, a finishing rolling completion temperature FDT within the range of 850 to 950°C should be used. When the FDT is less than 850°C, the deformation resistance of the rolling is great, the structure readily becomes heterogeneous, a laminar structure is formed and the workability declines. Meanwhile, when the temperature exceeds 950°C, grain growth occurs thereafter during cooling and a fine uniform structure cannot be obtained. As a result, the FDT should be 850 to 950°C.

[0030] Start of cooling after hot rolling is completed: within 0.5 seconds

Cooling should begin within 0.5 seconds after the hot rolling has been completed and cooling should be carried out at a cooling velocity of 30°C/s and above. When cooling is carried out after rolling, the structure of the hot rolled sheet obtained last of all becomes large and coarse. In the present invention, the average crystal grain size of the hot rolled sheet must be less than 4.0 μm to obtain an average crystal grain size for a cold rolled sheet of 5.0 μm and under. Forcible cooling must be carried out within 0.5 seconds after hot rolling so that the average crystal grain size of

the hot rolled sheet is less than 4.0 μm. When cooling starts after 0.5 seconds, the crystal grains become large and coarse and the average crystal grain size of the hot rolled sheet is 4.0 μm and above.

[0031] Cooling velocity for cooling after hot rolling is completed: 30°C/s and above

The cooling velocity after the hot rolling is completed should be 30°C/s and above. When the cooling velocity is less than 30°C/s, crystal grains grow after rolling is completed and a hot rolled sheet having an average crystal grain size of less than 4.0 μm cannot be obtained. Furthermore, the cooling velocity should be 60 to 100°C/s.

Winding temperature: 350 to 550°C

The hot rolled sheet which has been cooled should be wound in a coil immediately. The winding temperature should be 350 to 550°C. When the winding temperature is less than 350°C, a hard martensite phase is formed, the weight of the load during cold rolling increases and the rolling characteristics decline. In addition, when the winding temperature exceeds 550°C, the crystal grains become large and coarse making it impossible to obtain a fine structure and the characteristics following cold rolling and annealing decline. Furthermore, the temperature should be 400 to 500°C.

[0032] Thus, a hot rolled sheet having an extremely refined and uniform structure with an average crystal grain size of less than 4.0 μm can be obtained by adjusting the composition of the steel raw

material appropriately, carrying out hot rolling having a finishing rolling completion temperature within an appropriate temperature range and quenching immediately after rolling is completed. The hot rolled sheet has a uniform fine structure with an average crystal grain size of less than 4.0 μm so that distortions during the cooling and rolling are introduced to the steel sheet, thereby making it possible to recrystallize during subsequent annealing, to obtain an extremely uniform and fine structure during the phase transformation process and improving the flanging workability following cold rolling and annealing.

[0033] Here, we shall explain the results of experiments carried out on the effect of the average crystal grain size of the hot rolled sheet on the hole expanding workability for the cold rolled annealed sheet. We carried out hot rolling on an Nb group steel material having the following composition: C: 0.081 %; Si: 0.21 %; Mn: 3.14 %; P: 0.014 %; S: 0.0018 %; Al: 0.021 %; Ti: 0.015 %; and Nb : 0.042 % at a heating temperature of 1080 to 1300°C; and a finishing rolling temperature FDT of 900°C. We started cooling it within 0.3 seconds after the hot rolling was completed and produced the hot rolled sheet at a cooling velocity of 10 to 100°C/s and a winding temperature of 400°C. The relation between (a) the average crystal grain size of the hot rolled sheet at that time and (b) the hole expanding rate of the cooled and annealed sheet during hole expanding tests is indicated in Figure 1. Furthermore, cold rolling at a yield of 50 %, cold rolling

and annealing at an annealing temperature of 800°C and cold rolling-annealing at a post-annealing cooling velocity of 50°C/s and a quenching and cooling stopping temperature of 300°C were carried out on the hot rolled sheet, thereby producing a cold rolled annealed sheet. Furthermore, the A_{C3} transformation point of this material was 786°C. We found that the average crystal grain size of the hot rolled sheet was less than 4.0 μm and that the hole expanding ratio λ was at least 80 %.

[0034] Next, this hot rolled sheet was subjected to acid washing using the regular method and was then cold rolled, thereby providing a cold rolled sheet. The yield for the cold rolling should be at least 40 % from the vantage point of the refining of the structure of the cold rolled annealed sheet. By refining the crystal grains on the hot rolled sheet prior to cold rolling and making the structure uniform, a rolling distortion in the cold rolling is introduced to the steel sheet and an extremely uniform and fine structure can be obtained by recrystallization in the annealing thereafter and in the phase transformation process.

[0035] Annealing temperature for cold rolled sheet: (transformation point of A_{C3}) to (transformation point of A_{C3} + 100°C)

Annealing of the cold rolled sheet should be carried out by continuous annealing within an annealing temperature range of (transformation point of A_{C3}) to (transformation point of A_{C3} + 100°C). By controlling the annealing temperature to a high degree within this

narrow range, the crystal grains can be prevented from becoming larger and coarse and a cold rolled annealed sheet having a uniform fine structure can be obtained. When the annealing temperature is less than a transformation point of A_{C3}, the effect on the cold rolled structure remains and assumes a band-like structure and the desired objectives cannot be attained. Meanwhile, when the (point of transformation of A_{C3} + 100°C) is exceeded, the carbide becomes large and coarse and the crystal grains suddenly become large and coarse. A uniform refined structure cannot be obtained and the desired characteristics cannot be obtained. The ductility and other types of workability can be improved as is as well as the strength by refining the crystal grains.

[0036] The cold rolled sheet is quenched from the annealing temperature.

Quenching: up to a temperature region of 200 to 400°C at a cooling velocity of not less than 40°C/c and less than 100°C/s.

The cold rolled sheet is quenched up to a quenching stopping temperature range of 200 to 400°C from an annealing temperature at a cooling velocity of not less than 40°C/s and less than 100°C/s. When the cooling velocity is less than 40°C/s, the crystal grains become large and coarse, a large amount of the soft ferrite phase is generated and a tensile strength of at least 780 MPa cannot be obtained. In addition, the local strength difference increases, a great many starting points for cracks occur and the flanging

workability declines. Meanwhile, when the cooling velocity is 100°C/s and greater, the bainite phase softens so that the ductility and workability decline. In addition, quenching is carried out continuously in the present invention up to a quenching stopping temperature range of not more than 400°C and not less than 200°C. When the quenching stopping temperature is higher than 400°C, the pearlite phase and other soft phases are generated and the difference in strength with the low-temperature transformation phase increases and the flanging workability declines. At the same time, a tensile strength of 780 MPa or greater cannot be expected. Meanwhile, when the quenching stopping temperature is less than 200°C, a hard martensite phase is generated and the workability declines.

[0037] Thus, a cold rolled steel sheet with a uniform fine structure with a main bainite phase can be obtained by adjusting the composition of the steel raw material and by optimizing the hot rolling conditions and post-cooling annealing conditions. A high-strength cold rolled steel sheet with a high tensile strength of at least 780 MPa, a high strength-hole expanding ratio balance TS x E1 of 19000 MPa % and above can be obtained, a high strength-hole expanding ratio balance TS x λ of 74000 MPa % and above can be obtained with an excellent flanging workability.

[0038] [Practical Embodiment]

We took a cast having the composition indicated in Table 1 and made it into a slab (steel raw material) which was 260 mm thick using

the continuous casting method. Then, the slab was cooled to room temperature and reheated under the conditions indicated in Table 2. Hot rolling and post-rolling cooling were carried out under the conditions indicated in Table 2, thereby producing a hot rolled sheet (sheet thickness of 2.4 mm). Next, we subjected these hot rolled sheets to acid washing, carried out cold rolling at the cold rolling yield indicated in Table 2 and produced a cold rolled sheet (sheet thickness of 1.2 mm). Then, we annealed these cold rolled sheets at the temperatures indicated in Table 2 and after annealing them, we quenched them under the conditions indicated in Table 2.

[0039] We carried out structural tests, tensile tests and hold expanding tests on the cold rolled annealed sheets obtained. Furthermore, we measured the average crystal grain size for the hot rolled sheet. The test methods are as follows.

(1) Structural Test

We took a test piece from each of the hot rolled sheets and the cold rolled sheet from the rolling direction and from the direction perpendicular to the rolling direction. We observed the structure of the section in the rolling direction and the section in the direction perpendicular to the rolling direction, photographed it and measured the percentage of each phase and the crystal grain size using image analysis. We measured the crystal grain size for the entire thickness of the sheet on the section in the rolling direction and the section in the direction (C direction) perpendicular to the rolling direction

based on the stipulations of JIS G 0552 and indicated these as mean values.

(2) Tensile Test

We took a JIS No. 5 tensile test piece from the rolling direction for each of the cold rolled annealed sheets and from the direction (C direction) perpendicular to the rolling direction and studied the tensile characteristics (yield stress YS, tensile strength TS, elongation El).

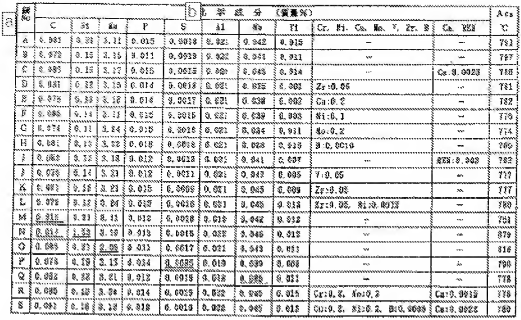
(3) Hole Expanding test

We punched holes measuring d_0 = 10 mmφ in the test pieces (sheet thickness x 100 x 100 mm) taken from each of the cold rolled annealed steel sheet based on the Japan Steel Association Standards JFST 1001, inserted conical punches having an apex angle of 60° from the opposite side of the burr side (side having a "burr" on the shearing face) and formed a hole and widened it. We found the hole diameter d (mm) when the cracks penetrated the thickness of the sheet and calculated the hole expanding rate λ. Furthermore, the hole expanding rate λ is defined as:

λ (%) = {[d - d_0] / d_0}] x 100.

[0040] Results are indicated in Table 3.

[0041] [Table 1]

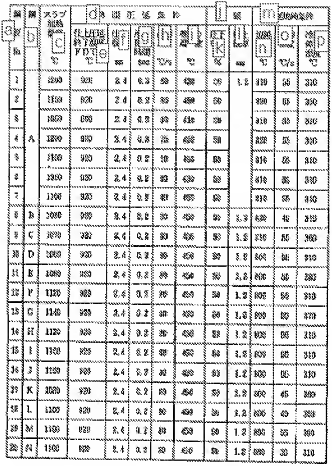


a 鋼No	b 化学成分（質量%）										Ac3
	C	Si	Mn	P	S	Al	Nb	Ti	Cr, Ni, Cu, Mo, V, Zr, B	Ca, REM	℃
A	0.081	0.33	3.11	0.015	0.0018	0.021	0.042	0.015	—	—	781
B	0.072	0.15	3.15	0.011	0.0028	0.022	0.041	0.021	—	—	787
C	0.083	0.15	3.17	0.016	0.0015	0.020	0.048	0.014	—	Ca:0.0028	758
D	0.081	0.22	3.15	0.014	0.0018	0.021	0.055	0.008	Zr:0.05	—	781
E	0.078	0.33	3.12	0.016	0.0017	0.021	0.038	0.008	Cu:0.2	—	782
F	0.085	0.11	3.13	0.016	0.0016	0.021	0.039	0.008	Ni:0.1	—	779
G	0.074	0.11	3.24	0.016	0.0016	0.021	0.034	0.011	Mo:0.2	—	774
H	0.081	0.13	3.22	0.019	0.0018	0.021	0.028	0.013	B:0.0010	—	760
I	0.083	0.12	3.18	0.012	0.0013	0.025	0.041	0.007	—	REM:0.002	782
J	0.078	0.14	3.21	0.012	0.0011	0.021	0.047	0.005	V:0.05	—	777
K	0.081	0.15	3.23	0.015	0.0008	0.021	0.045	0.009	Zr:0.05	—	777
L	0.078	0.13	3.24	0.015	0.0016	0.031	0.045	0.013	Zr:0.05, B:0.0015	—	780
M	0.212	0.21	3.11	0.012	0.0028	0.019	0.042	0.012	—	—	751
N	0.014	1.32	3.13	0.018	0.0015	0.022	0.046	0.015	—	—	879
O	0.085	0.23	2.08	0.013	0.0017	0.021	0.043	0.011	—	—	816
P	0.078	0.19	3.13	0.014	0.0085	0.019	0.039	0.008	—	—	798
Q	0.083	0.22	3.21	0.012	0.0015	0.018	0.009	0.011	—	—	778
R	0.085	0.15	3.34	0.014	0.0025	0.022	0.043	0.015	Cr:0.2, Mo:0.2	Ca:0.0015	778
S	0.083	0.18	3.18	0.018	0.0013	0.028	0.043	0.015	Cu:0.2, Ni:0.2, B:0.0008	Ca:0.0022	780

Key: a) Steel No; b) Chemical Constituent (percent by mass).

[0042] [Table 2]

[Table 2-1]

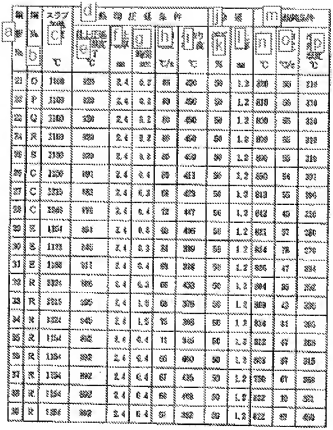


a No.	b	c スラブ加熱 ℃	d					j		m		
			e FDT ℃	f mm	g sec	h ℃/s	i ℃	k %	l mm	n ℃	o ℃/s	p ℃
1	A	1200	920	2.4	0.3	80	450	50	1.2	810	55	330
2		1150	920	2.4	0.2	80	450	50		850	55	330
3		1050	880	2.4	0.2	80	610	20		810	30	320
4		1250	920	2.4	0.3	25	650	50		820	55	330
5		1150	920	2.4	0.2	10	550	60		810	55	330
6		1050	920	2.4	0.2	80	450	50		610	35	330
7		1300	920	2.4	0.2	80	450	50		810	55	330
8	B	1200	920	2.4	0.2	80	450	50	1.2	820	45	350
9	C	1200	920	2.4	0.2	80	450	50	1.2	830	55	360
10	D	1200	920	2.4	0.2	85	450	50	1.2	800	50	310
11	E	1200	920	2.4	0.2	80	450	50	1.2	860	55	280
12	F	1150	900	2.4	0.2	80	450	50	1.2	800	58	300
13	G	1140	930	2.4	0.2	30	450	50	1.2	830	55	370
14	H	1120	920	2.4	0.2	80	450	50	1.2	800	55	330
15	I	1150	920	2.4	0.2	80	450	50	1.2	800	55	330
16	J	1150	920	2.4	0.2	80	450	50	1.2	800	55	330
17	K	1200	920	2.4	0.2	80	450	50	1.2	850	45	300
18	L	1100	920	2.4	0.2	80	450	50	1.2	800	40	300
19	M	1100	920	2.4	0.2	80	450	50	1.2	830	55	300
20	N	1100	920	2.4	0.2	80	450	50	1.2	830	35	310

Key: a) Steel Sheet No.; b) Steel No.; c) Slab Heating Temp. °C; d) Hot Rolling Conditions; e) Finishing Rolling completion Temp FDT °C; f) Finish Sheet Thickness mm; g) Cooling start time sec; h) Cooling velocity °C/s; i) Winding Temp. °C; j) Cold Rolling; k) Yield %; l) Finish Sheet thickness Mm; m) Cold Rolling Annealing Conditions; n) Annealing Temp. °C; o) Cooling Velocity °C/s; p) Cooling stop Temp.°C.

[0043] [Table 3]

[Table 2-2]

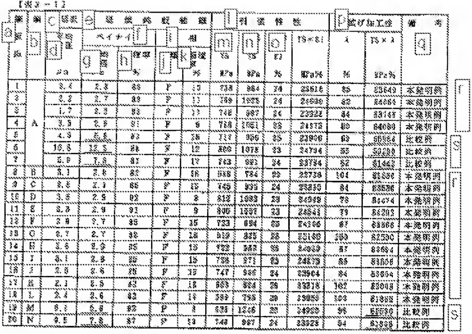


Key: a) Steel Sheet No.; b) Steel No.; c) Slab Heating Temp. °C; d) Hot Rolling Conditions; e) Finishing Rolling completion Temp FDT °C; f) Finish Sheet Thickness mm; g) Cooling start time sec; h) Cooling velocity °C/s; i) Winding Temp. °C; j) Cold Rolling; k) Yield %; l) Finish Sheet thickness Mm; m) Cold Rolling Annealing Conditions; n) Annealing Temp. °C; o) Cooling Velocity °C/s; p) Cooling stop Temp.°C.

[0044] [Table 4]

[Table 3-1]

【表3-1】



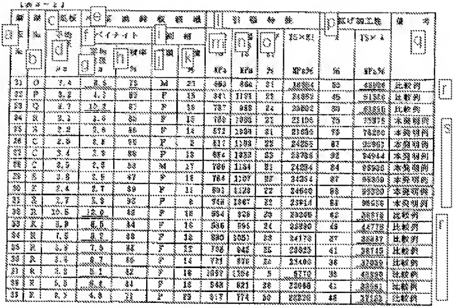
鋼板No.	鋼No.	熱延板 平均粒径 μm	冷延焼鈍板組織 ベイナイト 平均粒径 μm	ベイナイト 面積率 %	第二相 種類	第二相 面積率 %	引張特性 YS MPa	TS MPa	El %	TS×El MPa%	穴広げ加工性 λ %	TS×λ MPa%	備考
1	A	3.4	2.8	88	F	13	738	884	24	23616	85	83640	本発明例
2		3.3	2.7	89	F	11	789	1025	24	24600	82	84050	本発明例
3		1.7	2.3	88	F	11	748	987	24	23922	84	83148	本発明例
4		3.5	2.9	91	F	9	728	1051	22	24872	80	84080	本発明例
5		4.3	5.5	83	F	16	717	956	25	23900	63	56584	比較例
6		10.5	12.5	88	F	12	868	1078	23	24794	55	59290	比較例
7		5.8	7.8	83	F	17	743	982	24	23784	52	51443	比較例
8	B	3.1	2.8	82	F	18	588	784	29	22736	104	81536	本発明例
9	C	3.3	3.1	85	F	15	745	935	24	23830	84	83536	本発明例
10	D	3.3	2.5	92	F	8	812	1083	23	24909	78	84474	本発明例
11	E	3.8	2.9	91	F	9	890	1197	23	24841	79	86202	本発明例
12	F	2.9	2.7	85	F	15	723	894	28	24306	87	83366	本発明例
13	G	3.7	2.7	88	F	13	619	835	28	23180	100	82500	本発明例
14	H	3.5	2.9	85	F	15	722	943	25	24050	87	83694	本発明例
15	I	3.1	2.8	85	F	15	738	971	25	24275	85	81506	本発明例
16	J	2.8	2.5	85	F	15	747	986	24	23904	84	83654	本発明例
17	K	2.1	2.5	82	F	18	663	824	28	23218	102	83048	本発明例
18	L	2.4	2.6	83	F	17	589	788	30	23060	103	81888	本発明例
19	M	8.1	6.8	92	F	8	835	1246	20	24920	45	55530	比較例
20	N	4.5	7.8	87	F	13	748	987	24	23923	54	52938	比較例

P: pearlite; M: martensite; F: ferrite

Key: a) Steel Sheet no.; b) Steel No.; c) Hot rolled sheet; d) Average Grain size μm; e) Cold Rolled and Annealed Sheet Composition; f) Bainite; g) Aver. Grain size μm; h) Area ratio %; i) Secondary Phase; j) Steel sheet; k) Area ratio %; l) Tensile Characteristics; m) Yield point YS MPa; n) Tensile strength TS MPa; o) Elongation El %; p) Hole Expanding Workability; q) Remarks; r) This invention; s) Comparative Example.

[0045] [Table 5]

[Table 3-2]



P: pearlite; M: martensite; F: ferrite

Key: a) Steel Sheet no.; b) Steel No.; c) Hot rolled sheet; d) Average Grain size μm; e) Cold Rolled and Annealed Sheet Composition; f) Bainite; g) Aver. Grain size μm; h) Area ratio %; i) Secondary Phase; j) Steel sheet; k) Area ratio %; l) Tensile Characteristics; m) Yield point YS MPa; n) Tensile strength TS MPa; o) Elongation E1 %; p) Hole Expanding Workability; q) Remarks; r) Comparative Example; s) This invention.

The steel sheet in the present invention is a high strength cold rolled steel sheet having a structure which contains a fine bainite main phase at an area ratio of 80 % and above having an average crystal grain size of 5.0 *μ*m, having a tensile strength of 780 MPa and above; a TS x E1 avlue of 19000 MPa % and above; a TS x *λ* value of 74000 MPa % and above; an outstanding strength-expansion balance and outstanding strength-hole expanding ratio balance and outstanding flanging workability.

[0046] On the other hand, in the Comparative Examples which are outside the parameters of the present invention, the tensile strength TS was low or the TS x E1 value, TS x λ value were low and the workability deteriorated. Figure 2 indicates the relationship between the hole expanding ratio λ and the tensile strength for the cold rolled steel sheet (comparative examples) which lie outside the parameters of the present invention. The cold rolled steel sheet which satisfies the parameters of the present invention show a high λ value in all of the strengths and we found that it had outstanding flanging workability.

[0047] [Effect of Invention]

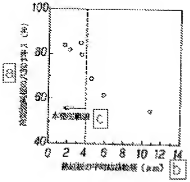
According to the process of the present invention, it has a high strength with a fine crystal grain having an average crystal grain size of 5.0 μm and under a tensile strength of 780 MPa. A high strength cold rolled steel sheet with outstanding strength-hole expanding ratio balance and flanging workability can be produced inexpensively thereby enhancing its effect in industry.

[Brief Explanation of Figures]

[Figure 1] A graph indicating the relation between the hole expanding ratio λ for the cold rolled and annealed sheet and the crystal grain size of the hot rolled sheet.

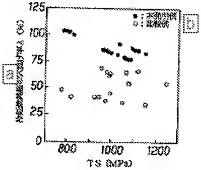
[Figure 2] A graph indicating the relation between the hole expanding ratio λ of the cold rolled and annealed sheet and the tensile strength TS.

[Figure 1]



Key:
a) hole expanding ratio λ of cold rolled and annealed sheet (%)
b) average crystal grain size (μm) [of the structure of the steel inside] the hot rolled sheet”
c) this part of the graph lies within the parameters of this invention

[Figure 2]



Key:
a) hole expanding ratio λ of cold rolled and annealed sheet (%)
b) • : this invention
O: comparative example